STATE OF CALIFORNIA
DEPARTMENT OF NATURAL RESOURCES

GEOLOGY OF THE SEBASTOPOL QUADRANGLE
CALIFORNIA

BULLETIN 162

1952

DIVISION OF MINES
FERRY BUILDING, SAN FRANCISCO

STATE OF CALIFORNIA
EARL WARREN, Governor
DEPARTMENT OF NATURAL RESOURCES
WARREN T. HANNUM, Director

DIVISION OF MINES
FERRY BUILDING, SAN FRANCISCO 11
OLAF P. JENKINS, Chief

San Francisco BULLETIN 162 October 1952

GEOLOGY OF THE SEBASTOPOL QUADRANGLE CALIFORNIA

By RUSSELL B. TRAVIS

LETTER OF TRANSMITTAL

To His Excellency
THE HONORABLE EARL WARREN
Governor of the State of California

SIR: I have the honor to transmit herewith Bulletin 162, *Geology of the Sebastopol Quadrangle,* prepared under the direction of Olaf P. Jenkins, Chief of the Division of Mines, Department of Natural Resources. The report is accompanied by various maps, charts, and illustrations, particularly a colored lithograph geologic map of the Sebastopol quadrangle, which lies in southwestern Sonoma County and northwestern Marin County. Attention is called to the relationship of the geology to the occurrence of economic mineral materials, such as sand and gravel, crushed rock, ground water, chromite, and other substances which have previously been exploited or may have potential possibilities.

The author, Russell B. Travis, mapped the geology of the area and prepared the report in partial fulfillment of the doctorate requirements at the University of California.

Respectfully submitted,

WARREN T. HANNUM, Director
Department of Natural Resources

August 20, 1952

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ILLUSTRATIONS

GEOLOGY OF THE SEBASTOPOL QUADRANGLE CALIFORNIA

By Russell B. Travis *

ABSTRACT

The Sebastopol quadrangle, comprising an area of about 245 square miles, is in the western Coast Ranges in Sonoma and Marin Counties about 45 miles north of San Francisco. It occupies for the most part a broad, uplifted, differentially dissected plain.

The rocks in the area, predominately sedimentary, range in age from Upper Jurassic to Recent. The oldest rocks, the Franciscan-Knoxville group, form the basement in the region and crop out primarily in the northwestern quarter of the quadrangle. They consist chiefly of sandstones of the graywacke type and interbedded shale, chert, and altered volcanic rocks; they have been intruded by diabase and serpentine. Metamorphic rocks of the glaucophane schist type are locally developed in the vicinity of serpentine and in a few places where no serpentine is apparent. In the southeastern part of the quadrangle, greenish clay of the Petaluma formation (middle or upper Pliocene) is in fault contact with Franciscan-Knoxville rocks. Both of the formations are unconformably overlain by the Merced formation (upper Pliocene) or by thin basalt flows which locally are interbedded with the Merced formation. The basalt flows are part of a thick series, the Sonoma volcanic rocks (upper Pliocene), which crop out primarily east of the Sebastopol quadrangle. The Merced formation, consisting chiefly of very fine-grained, massive, marine sandstone and some fresh water sand and gravel, forms a thin blanket over most of the central and southern part of the quadrangle. In many places it includes a thin bed of tuff-breccia. Overlying these formations are marine and river terrace deposits and valley alluvium.

The Franciscan-Knoxville rocks are complexly folded and faulted, but some broad northwest-trending folds can be recognized. The Petaluma formation is sharply folded, probably by the late Pliocene orogeny. The Merced formation has been broken by a series of high-angle faults as a result of Pleistocene uplift, northeast tilting, and settling movements of the San Francisco-Marin block which the quadrangle occupies. The large streams draining the area flow westward across the regional structure. Recent subsidence (or rise in sea level) is evidenced by the drowned mouths of these streams.

Most important mineral resources are sand and gravel and crushed rock. Chromite, copper, coal, building stone, gold, magnesite and garnets have been exploited at times.

INTRODUCTION

The Sebastopol quadrangle, comprising an area of approximately 245 square miles, is located in the Coast Ranges about 45 miles north of San Francisco. It occupies a local area of subdued topography and low altitude bordered on the north, east, and south by higher more rugged hills typical of the Coast Ranges. For about 3 miles in the southwestern corner, it borders the ocean. The quadrangle is readily accessible by several paved highways, most of which lead to Sebastopol, near the center of the area. Within the quadrangle good roads are numerous, and very few places are further than a mile from an all-weather road.

Field mapping of the Sebastopol quadrangle was done during the summers of 1948, 1949, and during short periods until June, 1950. The geology was plotted on a 15 minute topographic sheet (scale: 1:62500) of the United State Geological Survey.

Acknowledgments. This investigation was done under the direction of N. L. Taliaferro of the Department of Geological Sciences, University

* Condensation of a thesis submitted in partial fulfillment of the requirements for the degree Doctor of Philosophy, University of California, Berkeley, California. Manuscript submitted for publication February 1952.

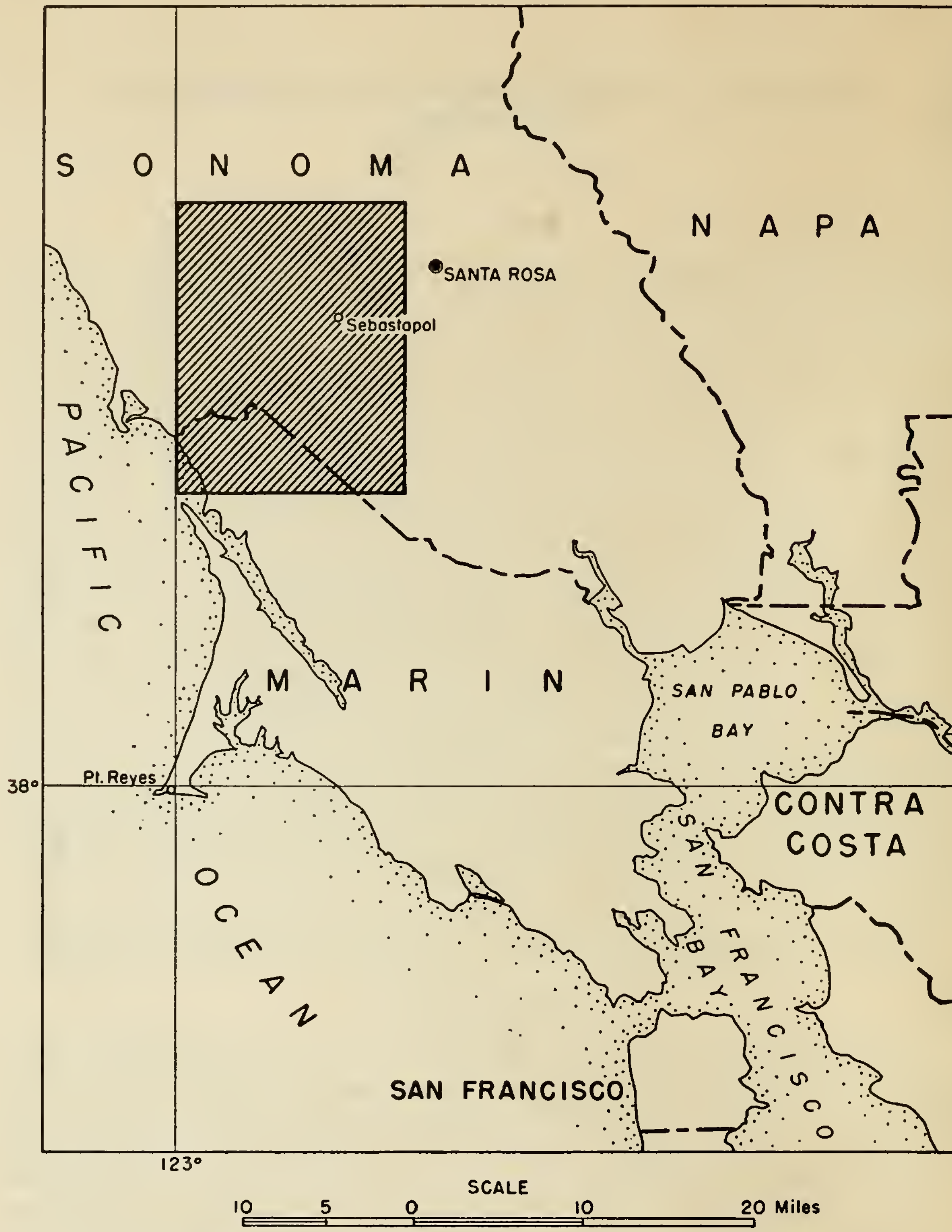

Figure 1. Index map showing location of Sebastopol quadrangle.

of California, Berkeley. Other members of this department who gave helpful criticism and suggestions are C. M. Gilbert, Adolf Pabst, F. J. Turner and Jean Verhoogen. Mahlon Kirk of the Department of Paleontology, University of California was very helpful in preparing and identifying fossils. J. W. Durham and D. E. Savage of the same department also identified many fossils, and suggested probable environments. Well drillers who gave freely of subsurface information are W. A. Duer, N. K. Keyt, and C. R. Woodbury. Land owners in the quadrangle were cooperative in allowing the writer access to private roads and property, and some gave helpful information about outcrops and fossil localitites.

Geography. The climate in this area is temperate, with well-pronounced wet and dry seasons. The rainy season is from November to March, and the average annual precipitation is about 30 inches. Temperatures range from about 90 degrees in the summer to about 40 degrees in the winter, although greater variations may occur in Santa Rosa Valley. Although most of the quadrangle is well populated, the bulk of the population is in Santa Rosa Valley and its bordering hills. Agricultural and resort operations are the chief sources of income.

The most conspicuous geomorphic feature in the Sebastopol quadrangle is the broad dissected plateau surface recognizable throughout the area between Santa Rosa Valley and the Pacific Ocean. The surface is best preserved in the southern half of the quadrangle, where it is expressed by flat topped hills and ridges. It rises northward and westward to a maximum elevation of about 1200 feet near Camp Meeker. In the northwestern corner of the quadrangle, where deeply entrenched meanders of the Russian River cut across the regional structure, the plateau surface has almost been obliterated by stream dissection.

The northwestern part of Santa Rosa Valley, a broad alluvial plain about 15 miles long and 7 miles wide, is in the Sebasopol quadrangle. Except for its northernmost part, which has been slightly dissected to form a series of low rolling hills, it is a nearly featureless plain.

The largest stream in the region is Russian River, which flows along the northern border of the quadrangle, entering it in only a few places. Tributaries of this river drain most of the northwestern part of the quadrangle as well as Santa Rosa Valley and its bordering hills. The rest of the quadrangle is drained by westward flowing Salmon, Americano, and Stemple Creeks and their tributaries.

A series of steps in the evolution of the present drainage system may be outlined. First the pre-Merced drainage system was obliterated by subsidence of the area and blanketed by deposition of the Merced formation. Following uplift, westward flowing consequent streams were established, and some subsequent tributaries developed as the Franciscan-Knoxville rocks were exposed. The next step was the eastward tilting of the region, which tended to reverse the flow of the consequent streams and increase the power of the tributaries to flow along structural features. Only the most powerful streams could maintain their westerly courses by cutting canyons through the growing barrier of Franciscan-Knoxville rocks near the present coast, thus becoming antecedent streams. Later tilting and uplift further modified the drainage to some extent, and as the most recent step, subsidence of the land or rise in sea level has drowned the mouths of major streams along the coast.

Previous Geologic Investigation. Early references to the geology of the Sebastopol quadrangle were made by J. D. Whitney [1] and A. C. Lawson.[2] The first detailed study was done by Osmont [3] in the preparation of his geologic sections across the Coast Ranges north of San Francisco Bay. Physiographic features are discussed in detail by Holway in his studies of the evolution of the Russian River [4] and of geomorphic features related to San Francisco Bay.[5] Johnson [6] made the first areal geologic map of the quadrangle in connection with his study of the Merced formation. He did not attempt to differentiate units in the Franciscan-Knoxville group or work out the structure of these formations. Weaver [7] mapped the geology of the Santa Rosa, Petaluma, and Point Reyes quadrangles, which adjoin the Sebastopol quadrangle on the east, southeast, and south. The geology of the Healdsburg quadrangle, immediately to the north, has been mapped by Gealey.[8] Higgins [9] has made a recent study of the geomorphology of the lower Russian River area, including the Sebastopol quadrangle.

GEOLOGY

Stratigraphy

Only a few formations, ranging in age from Upper Jurassic to Recent, are present in the Sebastopol quadrangle. The accompanying stratigraphic column shows the principal features of these formations. The most extensive exposures are of the Franciscan-Knoxville group, the Merced formation, and alluvium, which together cover almost the entire quadrangle. Other formations are limited to small scattered exposures. The Franciscan-Knoxville group forms most of the western part of the Coast Ranges north of San Francisco and is the basement rock throughout most or all of Sebastopol quadrangle. The Merced formation forms a thin blanket over much of the area and has a gentle north to northeast dip. Sandstone is by far the most abundant rock in the quadrangle, but other sedimentary, igneous and metamorphic rocks are abundant also.

Jurassic System

Franciscan-Knoxville Group. The basement rock in the Sebastopol quadrangle consists of a heterogeneous series of sandstone, siltstone, silty shale, conglomerate, radiolarian chert, and basic lavas, the lavas now largely altered to greenstone. This series is intruded by serpentine and by small bodies of diabase and gabbro. Metamorphic rocks of the glauco-

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[1] Whitney, J. D., Geology of California: California Geol. Survey, vol. 1, 1865.
[2] Lawson, A. C., Geomorphogeny of the coast of northern California: Univ. California, Dept. Geol. Sci. Bull., vol. 1, pp. 241-271, 1894.
[3] Osmont, V. C., A geological section of the Coast Ranges north of the Bay of San Francisco: Univ. California, Dept. Geol. Sci. Bull., vol. 4, 1904.
[4] Holway, R. S., The Russian River, a characteristic stream of the California coast: Univ. California Publ., Dept. Geog., vol. 1, 1913.
[5] Holway, R. S., Physiographically unfinished entrances to San Francisco Bay: Univ. California Publ., Dept. Geog., vol. 1, 1914.
[6] Johnson, F. A., The Merced Pliocene formation: unpubl., thesis, Univ. California, 1934. Johnson, F. A., Petaluma region: California Div. Mines Bull. 118, pp. 622-627, 1943.
[7] Weaver, C. E., Geology of the Coast Ranges immediately north of the San Francisco Bay region, California: Geol. Soc. America Mem. 35, 1949. Weaver, C. E., Geology and mineral deposits of an area north of San Francisco Bay, California: California Div. Mines Bull. 149, 1949.
[8] Gealey, W. K., Geology of the Healdsburg quadrangle, California: California Div. Mines Bull. 161, 1951.
[9] Higgins, C. G., Jr., The lower Russian River, California: Unpubl. thesis, Univ. California, 1950.

phane schist group are extensively developed in the vicinity of these intrusions and in a few places where no intrusions are apparent. On the basis of lithology, this series is referred to the Franciscan-Knoxville group of Upper Jurassic age.[10]

Detailed mapping in the Franciscan-Knoxville group is hampered by thick covers of vegetation or soil, and also by the structure of the rocks, which are severely crushed and sheared throughout much of the area mapped. In many areas, chert, sandstone, metamorphic rocks, and greenstone crop out together in small apparently unrelated masses, separated by pulverized material that is readily eroded and exposed only in cuts or cliffs. Large road cuts along the Russian River afford some exposures of this material and included blocks of other rocks.

Franciscan-Knoxville rocks are exposed in about one-third of the quadrangle, principally in the northwestern part. Throughout most of the remainder of the area, they are covered by Merced sandstone. Sandstone and siltstone predominate in the extreme northern part of the area, whereas intrusive and metamorphic rocks have their greatest development in the Camp Meeker-Occidental area. Exposures of these rocks in the southern half of the quadrangle are confined to valley bottoms, to blocks uplifted by faulting, or to high points on the pre-Merced erosion surface.

It is not possible to determine the total thickness of the Franciscan-Knoxville group because the base is not exposed, and overlying formations are separated from these rocks by an angular unconformity. However, between Camp Meeker and the Mountainview school to the north, about 7000 feet of probably unrepeated strata are involved in folds.

Megafossils were found in one locality. *Aucella piochii* (Gabb), a characteristic Franciscan-Knoxville fossil, has been identified from fragmentary material that was found in the sandy matrix of a conglomerate southwest of Occidental. Radiolaria are abundant in the chert, and in thin section several genera may be distinguished, although preservation is generally poor. However, stratigraphic significance of the radiolaria is not known at present.

Exposures in the Sebastopol quadrangle are too poor to determine definitely whether Franciscan-Knoxville rocks exist as separable lithologic units. Only one relatively small outcrop of black shale is designated in the report as Knoxville (?) shale.

Sandstone and siltstone of the "graywacke suite" [11] is by far the most abundant constituent of the Franciscan-Knoxville rocks in the Sebastopol quadrangle, comprising probably three-fourths of the total. The sandstone is characterized by firm induration, grain angularity, abundant rock fragments and fresh feldspar, small amount of matrix, and gray or green color. For the most part, it is medium-grained, but in the northwestern corner, fine-grained sandstone and siltstone predominate. Coarse-grained sandstone occurs in several places but is of limited extent. Both the coarse- and fine-grained sandstones are strongly resistant to erosion, but the fine-grained sediments weather more readily and are exposed only in road cuts or cliffs. Much of the coarse- and medium-grained sandstone, however, is so resistant that weathering produces topographic knobs nearly free of soil.

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[10] Taliaferro, N. L., Franciscan-Knoxville problem: Am. Assoc. Petroleum Geologists—Bull. vol. 27, pp 109-219, 1943.
[11] Pettijohn, F. J., Sedimentary rocks; Harper and Brothers Publs., New York, 1949.

AGE	FORMATION	COLUMN	FEET	DESCRIPTION
QUATERNARY	ALLUVIUM & TERRACES		Up to 300	Gravel, sand, clay
	~Unconformity~			
UPPER PLIOCENE	MERCED FORMATION		Up to 1000	Chiefly fine-grained, buff and gray, marine, feldspathic sandstone. Massive, friable, fossiliferous. Conglomeratic marine sandstone in western part of quadrangle. Some freshwater sands and gravels on west side Santa Rosa Valley. Thin bed of tuff breccia intercalated in marine sandstone in central part of quadrangle. Thin basalt flow of Sonoma volcanics at base in southeastern part of quadrangle, locally intercalated in sands and gravels.
	~Unconformity~			
MIDDLE OR UPPER PLIOCENE	PETALUMA FORMATION		Unknown	Thin-bedded, green and buff, discoidal clay in southeastern part of quadrangle. Base not exposed.
	Fault contact			
UPPER JURASSIC	FRANCISCAN-KNOXVILLE GROUP		7000+(?)	Sandstones of the graywacke suite with minor amounts of dark shale and conglomerate. Dark gray, thin-bedded, silty shale in Purrington Creek canyon assigned to Knoxville(?) formation, Jk. Chert, volcanic rocks, diabase. Serpentine intrusions with associated metamorphic rocks of the glaucophane schist series.

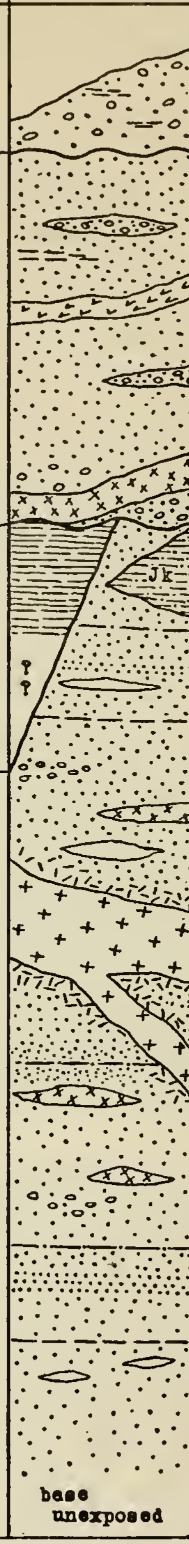


Figure 2. Stratigraphic column, Sebastopol quadrangle.

Bedding is restricted to the fine-grained sediments, and is especially well developed where fine-grained sandstone and siltstone alternate. The siltstone has a well-developed parting parallel to the bedding and a micro-joint system which, together, cause it to break into small rectangular blocks. Medium- and coarse-grained sandstone is generally massive, and gives no suggestion of attitude, except where it includes thin layers of shale. Jointing in the coarser-grained sediments is common, and is suggestive of bedding in some places, but, wherever the bedding is determinable, the two structures are independent. Sorting is poor in all the sandstone and graded bedding is rare.

Weathering transforms the gray or greenish-gray color of the fresh rock to brown or dark greenish-brown and, in many places, penetrates several feet into the rock. Thick mantles of decomposed sandstone cover many of the hills, especially those composed of fine-grained sediments.

The Franciscan-Knoxville sandstone has a relatively uniform composition in the Sebastopol quadrangle. It is composed essentially of quartz and feldspar with minor but significant amounts of rock fragments, biotite, muscovite, opaque minerals and carbonaceous material in a fine-grained matrix. In the hand specimen, quartz, plagioclase, rock fragments, and muscovite are readily recognized. Estimates of the proportions of minerals in thirteen thin sections average quartz 35 percent, feldspar 45 percent, and rock fragments 7 percent. The proportions of quartz range from 32 percent to 40 percent; of feldspar, from 30 percent to 54 percent. Alkali and plagioclase feldspar occur in the ratio of 1:2 or 1:3. The proportion of rock fragments ranges from 3 percent to 10 percent, about half of which is chert. Fragments derived from dense glassy lava and from chlorite-clinozoisitic rocks (?) are common, and shale fragments up to 2 inches long are locally abundant.

Biotite, more or less chloritized, is common throughout the sandstone. The amount ranges from 1 percent to 10 percent, increasing with decreasing grain size. Muscovite (less than 1 percent) as large pearly flakes is conspicuous in the hand specimen. Black opaque constituents include magnetite, ilmenite, hematite, pyrite, and carbonaceous matter. Carbonate minerals, predominantly calcite, ranging in amount up to 10 percent, occur in veins with quartz or in minor amounts as cement in some sandstones. Other minerals present in most of the thin-sections are: apatite, common; chlorite, alteration of biotite and in matrix, common; epidote-clinozoisite, common; garnet, colorless or pale pink, rare; rutile, rare; sphene, dark brown, slightly pleochroic, abundant; zircon, abundant.

Thin-bedded, silt- and clay-shale is sporadically interbedded with sandstone throughout the quadrangle. It is largely restricted to layers only a few inches or feet thick. Most of the shale is dark gray or black, but dark olive-green shales are common.

The section of dark-gray, very thin-bedded, brittle shale in the canyon of Purrington Creek about 1½ miles northeast of Occidental is designated as Knoxville (?) shale. It is at least 500 feet thick, and probably thicker. Although its exposure is restricted, it far exceeds the extent of any other shale in the area mapped. It is unfossiliferous, and no other rock-types were found interbedded with it.

The shale occupies the central part of a portion of the Camp Meeker syncline, and overlies the Camp Meeker serpentine sill and Franciscan-Knoxville sandstone of unknown thickness. It is separated from this sill by a few (?) hundred feet of sandstone and metamorphic rocks, but the contact with these rocks is not exposed. As may be seen in the accompanying geologic section, the sediments overlying the sill occupy a high stratigraphic position in the Franciscan-Knoxville rocks in this part of the quadrangle, although the stratigraphy of these rocks is imperfectly known. Therefore, although no fossils were found, it is designated Knoxville (?) shale on the basis of its stratigraphic position and lithology.

Franciscan-Knoxville conglomerate in the Sebastopol quadrangle is restricted to a few thin lenses of pebble and cobble material which are vaguely expressed in the topography. Pebbles are black and well-rounded; they consist, for the most part, of several kinds of porphyries, quartzite or recrystallized chert, and black chert. Pebbles of Franciscan-Knoxville sandstone and volcanic rock are present but rare. The porphyries include quartz porphyry, quartz-feldspar porphyry, and feldspar porphyry. A count of pebbles in some of these conglomerates reveals the following composition:

porphyries	80%
quartzite or recrystallized chert	10%
black chert	7%
other	3%

Chert is widely distributed throughout the exposed Franciscan-Knoxville group in the Sebastopol quadrangle, except in the extreme northwestern corner where it is conspicuously rare. Numerous large outcrops occur in the southern part of the quadrangle. The largest mass is about a mile east of Aurora school and is nearly a mile long and from 50 to 100 feet thick. No other large continuous masses were found. Few are over 100 feet long, and most of them are too small or too poorly exposed to map.

The character of the chert and its occurrence in this quadrangle are the same as elsewhere in the Coast Ranges. It is rhythmically-bedded radiolarian chert and crops out conspicuously in irregularly shaped masses of bare rock jutting abruptly above the ground. Individual beds of chert are from 1 inch to 4 inches thick and are generally separated by thin layers of shale. These beds are not of uniform thickness, but pinch and swell and lens out in short distances. Most commonly the chert is red in color, but in a few places it is green, black, brown, or white. Many of the chert lenses are severely contorted, brecciated, and veined with quartz, but others are quite undeformed.

Association of chert with greenstone is common, but most of the chert lenses are interbedded with sandstone and siltstone, and appear to be independent of greenstone.

Igneous Rocks. Franciscan-Knoxville volcanic rocks are widely distributed in the quadrangle, but do not comprise a great total thickness. They have been hydrothermally altered to fine-grained rocks of dull dark-green or greenish-brown color. As it is not possible to identify the original rock type in hand specimens, the term "greenstone" is used as a convenient field designation. The large bodies of greenstone have been mapped (pl. 1), but numerous other masses are too small to be included on a map of this scale. Much of the greenstone is intensely sheared, and commonly contains veins of quartz or calcite, or both.

Diabase occurs sparingly in the Franciscan-Knoxville group in the northwestern quarter of the quadrangle. It is altered to greenstone, and in the hand specimen most of it is indistinguishable from the volcanic rocks.

Serpentine, derived largely from alteration of the intrusive ultrabasic rocks peridotite and pyroxenite, is common in the Franciscan-Knoxville group in the quadrangle. The largest body is a sill exposed in both limbs of the Camp Meeker syncline. In the syncline two northwest-trending sub-parallel bands of serpentine crop out, exposed almost continuously over a length of about 6 miles. They coalesce about 1¼ miles north of Camp Meeker. The sill has an average thickness of about 1000 feet, with a maximum of about 2500 feet. None of the other serpentine bodies have outcrop lengths of over 1 mile.

Unweathered serpentine is dark olive-green when massive to light bluish-green when sheared, and has greasy to dull earthy lustre. Field appearance is largely determined by the amount of shearing. Outcrops of massive serpentine weather to rusty-brown or buff, rough blocky masses. When sheared it erodes easily, and exposures of such material are largely limited to road cuts.

Small disseminated grains of magnetite and chromite are sparingly present in all of the serpentine, although locally chromite is concentrated to form small deposits which were worked sporadically during World Wars I and II. Veinlets of chrysotile up to 6 or 7 millimeters wide trellis most of these rocks, and small veins or pods of magnesite are common.

Conspicuous and widespread, but not abundant, is the so-called silica-carbonate rock, a product of the hydrothermal alteration of serpentine.[12] As the name indicates, it is composed essentially of silica and a carbonate of calcium, iron, and magnesium. Because of its silica minerals it is much more resistant to erosion than the enclosing serpentine, and stands in conspicuous knobs and dikelike ridges, few of which are over 20 feet long in this quadrangle. It forms highly irregular buff or dark-brown outcrops. Leaching of the carbonate leaves a cellular meshwork of ocher-coated silica, producing a cavernous, jagged structure, which combined with the color, readily distinguishes it from other rocks.

Metamorphic Rocks. Metamorphic rocks are widely distributed and locally abundant in the Franciscan-Knoxville group in the Sebastopol quadrangle. They crop out in the vicinity of most of the serpentine bodies and in some places where no intrusive rock is apparent. Although not all these rocks are schistose, and glaucophane is absent from some, it is a major constituent in most of them and they are commonly referred to as glaucophane schists. The principal types are eclogite;[13] a series of rocks composed of some combination of quartz, glaucophane, actinolite, albite, epidote-clinozoisite, hornblende, garnet, lawsonite, chlorite, muscovite, stilpnomelane, zoisite, and pumpellyite; and metaspilitic rocks and metadiabases composed almost entirely of chlorite-clinozoisite or chlorite-lawsonite (or pumpellyite) with but minor amounts of glaucophane.

Well-crystallized, lustrous schists consisting largely of glaucophane, actinolite, or hornblende crop out conspicuously in knobs or short ridges. They are extremely hard and resistant to erosion, and in areas where they are abundant, form numerous rounded masses 20 or 30 feet in diameter. The most striking feature of the metamorphic rocks is their erratic distribution and apparent discontinuity over short distances. Masses of

[12] Knopf, Adolph, An alteration of Coast Range serpentine: Univ. California, Dept. Geol. Sci. Bull., vol. 4, pp. 425-530, 1906.

[13] Switzer, George, Eclogite from the California glaucophane schists: Am. Jour. Sci., vol. 243, pp. 1-8, 1945.

these well-crystallized schists in some places are abudantly distributed, yet no trace of metamorphism can be found in the intervening rocks which may include sandstone, chert, and greenstone. Although they are most abundant in the vicinity of serpentine bodies, no direct connections to the serpentine can be traced. Even where the rocks are in contact, or where metamorphic rocks are included in the serpentine, the relation is not gradational but abrupt, and the contact surfaces slickensided. These relations probably are the results of strong orogenic movements on rocks of diverse resistance.

Glaucophane schist is developed in the vicinity of all the serpentine bodies, but the most extensive development is near the Camp Meeker serpentine sill where all the varieties mentioned in this report may be found. Schist is locally abundant both above and below the sill, although along Dutch Bill Creek, below the sill it crops out almost continuously.

Eclogite occurs in abundant small masses and irregular veinlike bodies in the glaucophane schist. In general, eclogite is presumed to have been formed at extremely high pressures and temperatures. However, its close association with glaucophane schists indicates that here it probably represents relatively low grade metamorphism.

Most of the metamorphic rocks in the Sebastopol quadrangle have probably been formed by metasomatism related to the intrusion of basic and ultrabasic rocks, that involved the addition of lime and alumina, and the extraction of soda and silica.

Tertiary System

Petaluma Formation (Middle or Upper Pliocene). The Petaluma formation crops out only in a small area on the edge of the quadrangle 7 miles southeast of Sebastopol. Here it is exposed for a short distance in a narrow gully which cuts across the axis of an anticline. However, the presence of this formation is indicated in some low places along Gossage Creek by thick, black, sticky soil. In its only exposure it is composed of greenish and buff, well-bedded clay and is unconformably overlain by gravelly sand of the Merced formation and a thin flow of basalt of the Sonoma volcanic rocks. Absence of this formation over the greater part of the area is probably due to a period of uplift and erosion antedating deposition of the upper Pliocene Merced formation.

The base of the Petaluma formation is not exposed, making thickness determination impossible. Morse and Bailey [14] suggest a thickness of 4000 feet based in part on well data from the southeastern part of the Santa Rosa quadrangle. Northwest of Roblar, the formation is buried beneath the Merced formation, and southwest on the south side of the Tolay fault the Merced formation and Sonoma volcanics rest directly on Franciscan-Knoxville rocks.

The age of the Petaluma formation is in doubt because of lack of good fossil evidence. However, the best evidence seems to point to a middle or upper Pliocene age.[15]

[14] Morse, R. E., and Bailey, T. L., Geological observations in the Petaluma district, California: Geol. Soc. America Bull., vol. 46, pp. 1437-1455, 1935.

[15] Johnson, F. A., The Merced, Pliocene formation: Univ. California, unpub. thesis, 1934.
Stirton, R. A., Cenozoic mammal remains from the San Francisco Bay region: Univ. California, Dept. Geol. Sci. Bull., vol. 24, pp. 339-409, 1939.
Grant, U. S. IV, and Hertlein, L. G., Pliocene correlation chart: California Div. Mines Bull. 118, pp. 201-202, 1943.

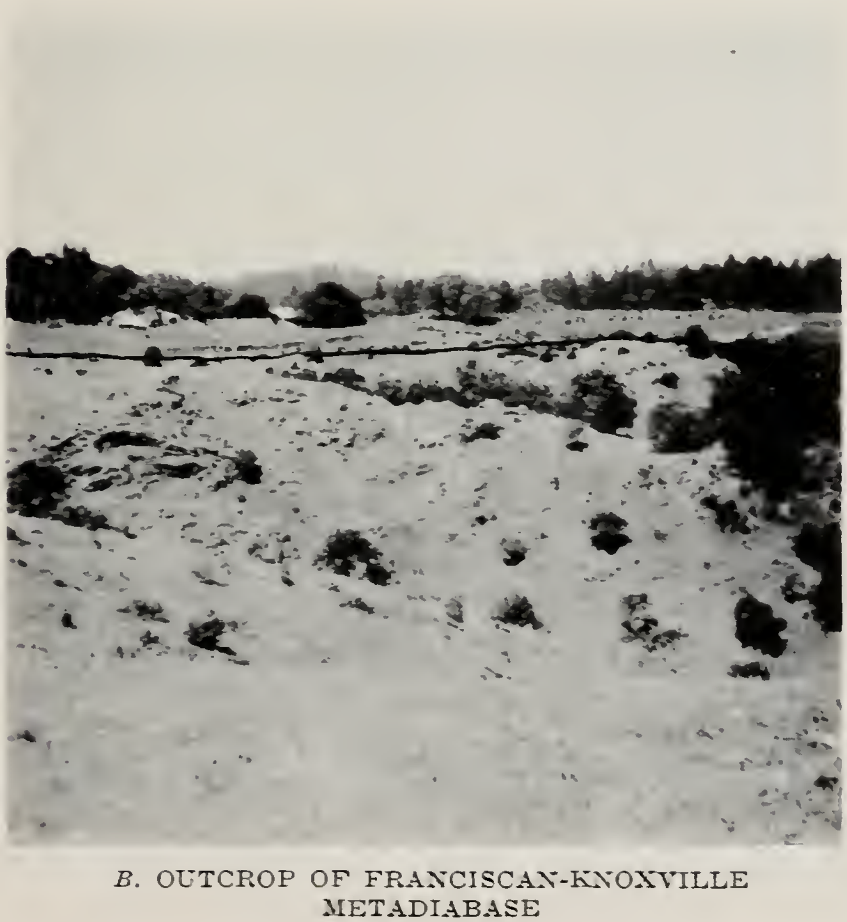
A. FRANCISCAN-KNOXVILLE FOSSILIFEROUS CONGLOMERATE

B. INTERBEDDED GREEN AND WHITE FRANCISCAN-KNOXVILLE CHERT

A. QUARRY IN FRANCISCAN-KNOXVILLE SILTY CHERT

B. PILLOW STRUCTURE IN FRANCISCAN-KNOXVILLE VARIOLITE

A. SERPENTINE BOULDERS IN SHEARED SERPENTINE



B. OUTCROP OF FRANCISCAN-KNOXVILLE METADIABASE

A. TRIANGULAR FACETS ON UPTHROWN BLOCK
North of Bloomfield fault.

B. LAVA FLOW OF SONOMA VOLCANIC ROCKS
On flank of Washoe Creek anticline.

Sonoma Volcanic Rocks. In the southeastern part of the Sebastopol quadrangle are several small exposures of thin lava flows. Some of them may be traced eastward into the Santa Rosa quadrangle where they become more continuous and thicker, and are associated with pyroclastic material. The volcanic materials represent the western fringe of the great mass of lavas, tuffs, and interbedded sands and gravels of the Sonoma volcanic rocks.

The lava flows in most places in this quadrangle rest unconformably on Franciscan-Knoxville rocks and are overlain by the Merced formation. However, north of Dunham school a flow of black olivine basalt is interbedded with gravelly sandstone of possible Merced age, which in turn overlies the Petaluma formation with strong angular unconformity. Thus at least part of the Sonoma volcanics may be contemporary with the Merced formation. The largest exposure of olivine basalt is southwest of Dunham school on the north flank of hill 713. Here it rests unconformably on Franciscan-Knoxville rocks and is overlain by the Merced formation. Elsewhere in this corner of the quadrangle small patches of basalt and olivine basalt crop out sporadically, many of them bordering faults.

All these lavas are light- to dark-gray to black. Porphyritic olivine basalts predominate but basalts occur also. Phenocrysts of olivine, augite, and plagioclase, up to 2 or 3 millimeters in maximum dimension, are megascopically recognizable in many of the lavas. In some, large phenocrysts of olivine and augite have been replaced by iddingsite, serpentine, chlorite, and iron oxide, forming conspicuous brown or green spots in the rock. Microscopically, most of the rocks are seen to be medium-grained, and to have a strong fluidal arrangement of crowded plagioclase laths, with abundant granules of augite and opaque minerals, and small amounts of interstitial glass. A typical mineral composition is: labradorite microlites 50 percent, groundmass augite 15 percent, labradorite phenocrysts 3 percent, augite phenocrysts 15 percent, olivine phenocrysts 10 percent, opaque minerals 5 percent.

A small plug (?) of hexagonally jointed tuff breccia of rhyolitic composition forms a small hill 2000 feet north of Dunham school. It intrudes the Petaluma formation and possibly the Merced formation, but its relation to the Sonoma volcanic rocks is not clear because of erosion. The rock consists of abundant white pumice fragments up to 3 inches in diameter, in a greenish-yellow groundmass of glass, quartz, sanidine, clastic grains, and opaque minerals. Probably the vent-breccia intrusion is about the age of the Sonoma volcanic rocks.

Merced Formation (Upper Pliocene). The Merced formation, consisting of both fresh-water and marine buff and gray sandstones and lenses of conglomerate and sandy shale, is the most widely distributed formation in the Sebastopol quadrangle. The marine sandstone, which interfingers with the fresh-water sediments and Sonoma volcanic rocks, includes a thin bed of tuff breccia. It is predominantly very fine-grained, argillaceous, feldspathic, and fossiliferous. The fresh-water part of the Merced formation consists chiefly of gravel and medium-grained sandstone intergrading within short distances, but includes a few lenses of sandy clay. Calcium carbonate and iron oxide concretions, commonly containing fossils, are numerous and widely distributed in the formation.

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The formation covers about three-fifths of the Sebastopol quadrangle, including the south-central part of the northern half and almost all the southern half. Thin patches of Merced cap most of the flat-topped hills in the western part of the quadrangle, except in the northwestern corner. The exposures of the fresh water part of the Merced formation are confined to the western edge of Santa Rosa Valley. The most extensive exposures are along the Guerneville Highway northeast of Sousa Corners, in and around Sebastopol, and the area east of Cadwell and Hessel near the eastern margin of the quadrangle. The Merced formation is found also along the northern border of the Pt. Reyes quadrangle and in the Santa Rosa, Petaluma, and Mare Island quadrangles, northwest and southeast of Petaluma.[16] The exposed thickness of the Merced formation ranges from a few feet to about 500 feet. The persistent gentle northeast dip indicates that the thickness is greatest near the western edge of Santa Rosa Valley. Fresh-water deposits interfinger with the marine part of the Merced formation along the western edge of Santa Rosa Valley and probably thicken eastward but are not over 200 or 300 feet thick where they are exposed.

Total cumulative thickness of the Merced formation cannot be reliably estimated because of the general absence of horizon markers and the irregularity of the surface upon which it rests. An interbedded tuff breccia, which is a good time marker over part of the area, is underlain by a maximum of 250 feet and overlain by a maximum of 200 feet of marine fine-grained sandstone. In the southwestern part of the quadrangle, about 300 feet of conglomeratic marine sandstone rests on the Franciscan-Knoxville group and grades upward into the typical fine-grained marine sandstone.

Table 1. Composition of Coarse-Grained Merced Sediments.

Rock type	Marine conglomeratic sandstone (percent)	Fresh water conglomerate (percent)
Chert	50	65
Quartz	30	25
Sandstone and schist (Franciscan-Knoxville)	10	5
Quartzite	8	4
Other	2	1

Throughout most of its extent in the area, the Merced formation rests on an irregular erosion surface of considerable relief cut in rocks of the Franciscan-Knoxville group. Because the slopes of this erosion surface are in many places steep, there is a great irregularity in thickness of the Merced, and the Franciscan-Merced contact is erratic in nature. The maximum relief on this surface exposed at the present time is about 500 feet. In a small area north of Dunham school, and for an unknown distance to the northwest, the Merced formation unconformably overlies the Petaluma formation. In some places the Merced formation is unconformably overlain by Quaternary alluvial gravels and terrace deposits.

Almost all the Merced sandstone is massive, loosely-packed, and poorly cemented by argillaceous material and iron oxide. Locally, zones containing fossils are firmly cemented with calcium carbonate. Crossbedding is not uncommon in the fresh water part of the Merced formation.

[16] Weaver, C. E., op. cit., California Div. Mines, Bull. 149, 1949.

In the southern half of the quadrangle, the sandstone includes more resistant beds which are conspicuous in gullies but are rarely traceable between them.

Conglomeratic, gritty sandstone, common in the southwestern corner of the quadrangle, caps small buttes near Valley Ford, and has been carved by erosion into large, bold structures which stand out conspicuously on the landscape. However, these more resistant phases are of local extent and grade laterally into non-resistant gravels and sands which readily disintegrate.

The bulk of the marine Merced sandstone is subangular, well sorted, and very fine-grained. Mechanical analyses of five samples showed that 75 to 94 percent of the sand is composed of grains between 0.2 and 0.05 millimeter in diameter. Most of the remaining material is finer grained. Both the marine conglomerate sand and the fresh-water sand and gravel range considerably in sorting.

F. A. Johnson [17] made an extensive petrographic study of the Merced formation. Some of his results have been confirmed by the writer and are included in table 2. This table shows the average mineral composition of the principal types of Merced sandstone, which does not differ significantly from place to place within the area studied. Pebble counts from the coarser deposits indicate that well-rounded and highly polished chert and quartz predominate. The results of several counts are summarized in table 1. Most of the chert pebbles are radiolarian and similar to that found in the Franciscan-Knoxville rocks.

A highly tuffaceous sandy conglomerate occurs in the hills just east of Sousa Corners. Over half of this conglomerate is composed of fine tuffaceous material and rounded pebbles of decomposed pumice as much as

Table 2. Mineral Composition of Merced Sandstone.

Mineral	Fine-grained marine sandstone	Conglomeratic marine sandstone	Fresh-water sandstone
Plagioclase	45	38	30
Quartz	20	22	35
Orthoclase	17	15	15
Rock fragments	10	15	10
Chert	8	10	10
Volcanic glass	pr	pr	pr
Heavy minerals	0.5	1.0	0.5
Magnetite	5.0	1.0	3.5
Non-magnetic iron ore	15.0	11.0	15.0
Lawsonite	6.5	5.5	5.0
Glaucophane	3.0	3.0	3.5
Zircon	3.5	2.5	1.5
Green hornblende	3.0	pr	5.0
Actinolite	1.5	2.0	2.0
Sphene	1.5	1.0	1.5
Garnet	0.5	1.5	1.0
Epidote	1.0	1.0	pr
Rutile	pr	pr	pr
Zoisite	pr	pr	pr
Basaltic hornblende	pr	rare	1.0
Tourmaline	pr	pr	pr
Muscovite	pr	rare	rare
Biotite	pr	rare	pr
Augite	rare	rare	pr
Hypersthene	rare	rare	pr

[17] Johnson, F. A., The Merced Pliocene formation: Univ. California, Unpub. thesis, 1934.

1 inch in diameter. The remainder corresponds approximately to the composition of fresh water conglomerate given in table 1.

A few small exposures of lignitic coal occur in Merced fresh-water sand and gravel from a half to three-fourths of a mile west of Trenton on the River road. Water wells in this area penetrate lignite beds 5 to 10 feet thick at variously reported depths.

Tuff Breccia. A thin but persistent bed of water-laid tuff breccia, interbedded with Merced sandstone, crops out over wide areas in the central and northern part of the area. The white spots it forms on hillsides stand out conspicuously. In many areas, however, it is obscured by vegetation or soil. It can be traced almost continuously from a point 1¾ miles west of Dunham school, where it is but a few inches thick, to Jonive school, east of Occidental. Near Jonive school it averages about 10 feet in thickness, and is interbedded with marine, buff, fine-grained sandstone with little tuffaceous material. Here it ranges from 50 to 250 feet stratigraphically above the base of the Merced formation. In the hills on either side of Mark West Creek northwest of Trenton, sandy tuff breccia crops out abundantly. On the south side of the creek outcrops are small and erratically distributed, but on the north side the tuff breccia crops out continuously for about a mile and has an estimated thickness of 50 feet. Careful searching by the writer failed to reveal any trace of tuff breccia between the two areas, and it is doubtful that the two occurrences represent a single bed.

Glass and pumice fragments as much as 4 inches long are predominant constituents in the tuff breccia from both areas. Near Trenton, the tuff includes about 25 percent of sand and pebbles, but, elsewhere it contains only minor amounts of clastic material. Some tuff, composed exclusively of fine ash, occurs locally. Fossils occur in the tuff breccia near Freestone and, although "marine in character," are indeterminate.[18]

The source of the pyroclastic material in the tuff breccia is not known. The thickest accumulation of the Sonoma volcanics is east of the Sebastopol quadrangle, and it is possible that the pyroclastics came from that direction. Johnson [19] found a volcanic neck in the northeastern part of the Bodega Head quadrangle, and suggested that as a possible source. However, there is no evidence to support this view. The vent breccia near Roblar may represent the source, but the tuff breccia is thicker to the north and west.

The Merced formation is probably upper Pliocene in age. Although fossils are abundant in the formation, they are not diagnostic. Specimens were collected from several localities and submitted to J. W. Durham and Mahlon Kirk, in whose opinion they indicate Pliocene age, more likely upper than lower.[20] Species determinations, as well as localities from which the specimens were collected, are listed in table 3.

The most prolific source of Merced fossils is in the Healdsburg quadrangle at Wilson Grove, 2 miles north of Trenton. The fauna of this

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[18] Osmont, V. C., A geological section of the Coast Ranges north of the Bay of San Francisco: Univ. California, Dept. Geol. Sci. Bull., vol. 4, 1904.
[19] Johnson, F. A., op. cit.
[20] Personal communication.

Table 3. Fossils From Merced Formation.

	Location*					
	C-13	M-2	L-16	C-17	X	Y
Pelecypoda:						
Anadara trilineata (Conrad)	X					X
Cryptomya californica Conrad			X			X
Glycymeris sp.					X	
Macoma nasuta (Conrad)	X					
cf M. secta (Conrad)						X
sp.			X			
Marcia angustifrons (Conrad)					X	
Mytilus sp.						X
Prototheca staleyi (Gabb)	X			X		X
Pecten (patinopecten) healeyi Arnold		X				
Solen sp.					X	
Spisula cf S. albaria (Conrad)	X					
sp.				X		X
Tellina sp.					X	
Gastropoda:						
Crepidula princeps Conrad					X	
Miopleionia sp.					X	
Nassarius californicus (Conrad)	X			X		
Olivella pedroana	X					
Polinices sp.	X					
Coral (?)			X			
Coronula (?) sp.			X			

* Locations:
C-13——Creek bed, three-quarters of a mile south of Vine Hill School, near Trenton.
M-2——Road cut, $2\frac{1}{4}$ miles northeast of Dillon Beach.
L-16——Road cut, $2\frac{1}{2}$ miles west of Dunham school.
C-17——Creek bed, 1,800 feet N. 58 E. of hill 426, 1 mile west of Trenton.
X——Fossils found commonly in concretions in southwestern part of quadrangle.
Y——Fossils found commonly as sand casts and rarely composed as original material throughout the fine sand.

locality has been collected by Staley,[21] Osmont [22] and Dickerson,[23] all of whom regarded them as Pliocene, and at least in part equivalent to the type Merced of the San Francisco peninsula. Charles Merriam suggested that the Wilson Grove fauna indicates middle Pliocene age. Weaver concluded that the fauna from Wilson Grove and other Merced localities "is probably of middle Pliocene age." [24] However, in the Sebastopol quadrangle the Merced formation rests unconformably on the middle to upper Pliocene Petaluma formation, and it is considered here to be upper Pliocene in age.

The Merced formation was derived primarily from rocks of the Franciscan-Knoxville group, and was deposited in a relatively shallow marine embayment which opened to the ocean to the west. The eastern border of this embayment was near the present western edge of Santa Rosa Valley, but was not constant in its position. No marine Merced is known on the east side of this valley, and hence the maximum eastern transgression of the Merced sea was located somewhere in the site of the present Santa Rosa Valley.

[21] Gabb, W. M., Paleontology of California : California Geol. Surv., vol. 2, 1869.
[22] Osmont, V. C., A geological section of the Coast Ranges north of the Bay of San Francisco : Univ. California, Dept. Geol. Sci. Bull., vol. 4, 1904.
[23] Dickerson, R. E., Tertiary and Quaternary history of the Petaluma, Point Reyes and Santa Rosa quadrangles: California Acad. Sci. Proc., 4th ser., vol. XI, pp. 527-601, 1922.
[24] Weaver, C. E., op. cit., California Div. Mines Bull. 149, 1950.

Table 4. Typical Composition of Pleistocene Gravel in Santa Rosa Valley.

	Percent
Acidic lavas (including vesicular, pumiceous, and banded varieties)	45
Intermediate lavas (gray-colored, dense, non-vesicular types)	20
Basic lavas (black, dense, fine-grained rocks possibly including some andesites)	12
Franciscan-Knoxville chert (red, green, and brown)	10
Other Franciscan-Knoxville rocks	5
Obsidian	3
Tuff or tuff-breccia	3
Petrified wood	2

The presence of *Crepidula princeps* Conrad in conglomeratic sandstone from a mile north of Bodega to Dillon Beach indicates that this stretch was on the open ocean, at least during early Merced time. All the other fossils are of forms which prefer quiet, relatively shallow water, protected from heavy waves. The fineness of the sand also attests quiet water. According to Clark [25] the climate during Merced time was "cold-temperate to boreal" and on the basis of the fossils collected by the writer, Mahlon Kirk [26] suggests the climate was probably somewhat cooler than at present. Carbonaceous material and fragments of wood are common in the Merced and well-preserved logs have been penetrated by drilling.

Quaternary System

Pleistocene deposits are neither abundant nor thick except in Santa Rosa Valley. Here they compose a 100 foot terrace which is being dissected by streams. The terrace is most conspicuous where Mark West Creek has cut a shallow valley in it about half a mile wide. Northwest of Trenton the 100 foot terrace is clearly expressed on most of the bordering slopes, where the terrace gravels rest on Merced sandstone or tuff breccia. Southward and eastward, this terrace merges imperceptibly with the alluvial deposits of the greater part of Santa Rosa Valley. Therefore, it is included on the map with older alluvium.

These terrace deposits are composed of gravel and gravelly sand, and were largely derived from volcanic rocks.

Buff or reddish-brown gravelly sands are common on marine terraces north of Dillon Beach. These deposits are 10 or 15 feet thick and consist exclusively of Franciscan-Knoxville and Merced debris. They are well-stratified, and some have primary dips up to 20 degrees.

Small patches of stream deposits were found at several levels along the Russian River, but were not mapped. Notable occurrences are in the hills west of Northwood in the northwestern corner of the quadrangle, and at about the 200 foot level in the hills southeast of Mirabel Park.

[25] Clark, B. L., Stratigraphy and faunal horizons of the Coast Ranges of California: Private publication, 1929.

[26] Personal communication.

They consist of buff to dark-brown gravel and coarse sands composed of Franciscan-Knoxville and volcanic rocks. A large terrace deposit at an altitude of about 200 feet covers the hill a mile northeast of the Mark West Creek-Russian River confluence. Many vertebrate fossils of ''later Pleistocene'' age have been found in the gravels along Estero San Antonio, about a mile from its mouth.[27] Among them a bison, *Mammuthus, cf., columbi*, and *Mammut cf., americanum* have been recognized.

Recent alluvium fills many of the stream valleys in the quadrangle and consists of gravels, sands, and clays. In the lower part of Laguna de Santa Rosa, in Green Valley Creek, and in the esteros to the south, alluviation has developed marshes. Landslides are abundant in the Sebastopol quadrangle. Although most are small, some of moderate size occur in the Franciscan-Knoxville rocks southwest of the Camp Meeker syncline.

Structure

The geologic structure of the Merced formation in the Sebastopol quadrangle is relatively simple, but the structure of the underlying Franciscan-Knoxville group is complex. Although the details of structure of these basement rocks are difficult to obtain, it is clear that they are complexely folded and faulted, and, like the Franciscan rocks in other parts of the Coast Ranges, have a general NW-SE structure. The Merced formation forms a thin blanket over this basement and, in most of the quadrangle, is nearly horizontal and undulating, although northeast dips greatly predominate. This may be accounted for by a series of northwest-trending faults of small to moderate displacement that break the region into several blocks tilted to the northeast. Although the structure of the Merced formation is simple, details are obscured by poor exposures, homogeneity of much of the formation, and lack of bedding. An intercalated tuff breccia in the central part of the quadrangle and thin lava-flows of the Sonoma volcanics in the southeastern part outline the structure in those regions.

Although the San Andreas fault passes through the water-covered southwestern corner of the quadrangle, no other large Tertiary fault-systems are present and the entire region is confined to Lawson's San Francisco-Marin Block.

Faults

Faults in the Sebastopol quadrangle may be separated into two groups; those of pre-Merced, and those of post-Merced age. The pre-Merced faults, with the exception of the Tolay fault involve only rocks of the Franciscan-Knoxville group. Although these rocks are intricately faulted, only a few pre-Merced faults have been shown on the map. In a strict sense, many of the contacts between members of the Franciscan-Knoxville group are probably fault contacts, as most of them show signs of movement. This applies to the Camp Meeker serpentine sill as well as to smaller bodies. However, as these movements are probably of small displacement, it is felt that a more accurate impression is given by plotting the contacts as unfaulted. In the Franciscan-Knoxville rocks west of Forestville, two faults are shown. The location of the larger one is determined by gouge and crush zones which appear to belong to a single fault or narrow fault zone. This fault extends northeastward into the Healds-

[27] Personal communication.

burg quadrangle and is part of the Mt. Jackson fault zone.[28] The shorter one has brought chert and metamorphic rocks which are, in part, brecciated into contact with sandstone. This fault can be recognized for only a short distance beyond the exposure of the metamorphic rocks, which are rare in this part of the quadrangle. Another of these faults is located a mile north of Dillon Beach. Here a shear zone, 50 to 100 feet wide including blocks of brecciated, recemented graywacke, is clearly exposed along a cliff. It can be recognized for about half a mile to the southeast, where it passes beneath the Merced formation. None of these faults has affected the Merced formation.

The Tolay fault, best expressed in the Santa Rosa and Petaluma quadrangles extends from San Pablo Bay for over 20 miles into the Sebastopol quadrangle north of Dunham school. Here it brings Franciscan-Knoxville rocks on the southwestern side of the fault into contact with the Petaluma formation on the northeastern side. The post-Merced movement of this fault consisted of small, mainly vertical, displacement [29] and has been insufficient to expose the rocks underlying the Merced formation beyond a mile northwest of Dunham school. The main activity along this fault took place after Petaluma time and before Merced time.

The post-Merced faults have many characteristics in common. With few exceptions they are nearly vertical, trend northwestward, and have small displacements uplifting the northeast blocks. As a result the blocks have been slightly tilted to the northeast. These faults bring Franciscan-Knoxville rocks into contact with the Merced formation. In the Trenton-Forestville area, movements along two nearly vertical faults have produced a series of steep hills. One of these faults borders the range of hills about a mile east of Forestville, and extends northwestward into the Healdsburg quadrangle. To the southeast, it is lost in the Merced formation. It probably has controlled the drainage of the small creek south of the Vine Hill school, and intersects, or is continuous with, the nearly north-south fault east of Sousa Corners. The movement on the fault east of Forestville has been vertical, as far as can be ascertained, and has uplifted the northeastern block and tilted it northeastward. The maximum displacement is over 300 feet but probably less than 400 feet. The fault contact is exposed in a small road cut just south of hill 516 and at this place it dips steeply to the east. However, the soft incoherent Merced sand makes such evidence inconclusive and it would not be safe to say that the fault is a high-angle thrust. Another fault, just east of Trenton, passes beneath terrace deposits to the north and beneath valley alluvium to the south. It brings up Franciscan-Knoxville metamorphic rocks, chert, sandstone, and a small patch of serpentine on the northeastern side of the fault. The Merced formation borders the fault on the southwest. The maximum displacement is at least 250 feet and is probably over 300 feet.

Most of the post-Merced faults are in the southeastern quarter of the quadrangle. Two of these, the Bloomfield fault and the Americano Creek fault, have developed a graben structure in the Bloomfield area. The Bloomfield fault extends from a mile north of Walker school northwestward about eight miles, where it apparently dies out. It has a strong expression in the topography. Over most of its extent this fault has brought

[28] Gealey, W. K., Geology of the Healdsburg quadrangle, California: California Div. Mines Bull. 161, 1951.
[29] Weaver, C. E., op. cit., California Div. Mines Bull. 149, 1950.

up Franciscan-Knoxville rocks on the northeastern side into contact with Merced sandstone. The maximum vertical displacement is probably over 600 feet. The Americano Creek fault extends along the range of hills south of Americano Creek. It is the only fault known in the quadrangle in which the south block has been upthrown. It extends from a mile east of Two Rock to a mile southwest of Bloomfield, a distance of about 6 miles. This fault is nearly vertical, and has a maximum vertical displacement of at least 300 feet south of Bloomfield.

The Dunham fault, just south of Dunham school, has upthrown Franciscan-Knoxville rocks on the northeast into contact with the Merced formation and Sonoma volcanic rocks. The maximum displacement is over 300 feet but is probably less than 400 feet. There are three other high-angle faults in this area, but they are much smaller than those discussed above. The upthrown north-side blocks bring Franciscan-Knoxville rocks into contact with Merced sandstone. The displacements are at least 100 feet, and probably near 200 feet. They are about 2 or 3 miles long. A small fault of 100 or 200 feet maximum displacement occurs north of Walker school.

Another series of faults occurs north of Bodega in the west-central part of the quadrangle. The tracing of these faults is greatly handicapped by thick soil and timber, and by the absence of the usually common rocky outcrops of the Franciscan-Knoxville group. In this area, three faults have been mapped. They are high-angle, of moderate displacement, with the north blocks upthrown. The largest of these, called herein the Joy Woods fault, is about 3½ miles long. Metamorphic rocks are abundant on its north side. The maximum vertical displacement is about 300 feet. The other two faults in this group are similar to but smaller than the Joy Woods fault. The larger of the two is well expressed in the topography and has a maximum displacement of about 300 feet.

The similarities of the post-Merced faults in the Sebastopol quadrangle clearly indicate a common origin. This region occupies a block which is an extension of the San Francisco-Marin block bounded on the west by the San Andreas fault system and on the east by the possible extension of the Hayward fault. During Pleistocene time, probably during the mid-Pleistocene orogeny, this block was uplifted and tilted to the east. It is probable that concurrent and subsequent settling movements developed the series of faults described above. Some of these are perhaps reactivations of older faults, as the general strike of the post-Merced faults is about the same as the regional strike in the Franciscan-Knoxville group.

Folds

Some broad structural features can be deciphered in the Franciscan-Knoxville rocks. The most clearly defined structure is the Camp Meeker syncline, delineated by the Camp Meeker serpentine sill. The exposure of metamorphic rocks and a few small serpentine masses along the general strike of this sill strongly suggest its extension to the area around Two Rock in the southeastern part of the quadrangle. It plunges gently to the south, disappearing beneath the Merced formation southeast of Occidental. Its strike ranges from about N. 50° W. in the southeastern part of its outcrop to about N. 30° W. in the northwestern part. It is somewhat asymmetric, the steeper northeastern limb dipping to the southwest nearly 90 degrees, but the dip of this limb is difficult to determine. Two other broad folds are shown in the Franciscan-Knoxville rocks, but their locations are vaguely defined and can only be approximated. Both are located in heavily timbered regions and no details of their structure can be given.

In spite of the prevalence of northeastward dips in the Merced formation, there is evidence of undulation, as indicated by the fact that over much of the area the thickness of the formation is relatively uniform. A small, sharply asymmetric syncline involving a lava flow of the Sonoma volcanic rocks and the Merced formation has been caused by fault drag on the south side of the Dunham fault. The lava adjacent to the fault dips 60 to 70 degrees to the west whereas the lava half a mile southwest dips about 6 degrees to the east.

The only clearly defined folding in the Merced formation occurs north of Dunham school. Here, the Washoe Creek anticline of the Santa Rosa quadrangle broadens out and splits into two low anticlines and included syncline. A basalt flow of the Sonoma volcanics, intercalated with Merced gravels, delineates the structures in the area.

Intensely folded Petaluma clays form the core of the folds, and farther east are overlain directly by basalt, but they have too limited an exposure here to determine much of their structure. Dips of the basalt on the flanks of these folds do not exceed 15 degrees. The axis of the north anticline, which is a direct extension of the Washoe Creek anticline, strikes about N. 65° W., whereas that of the south anticline passes through Roblar and strikes about N. 75° W. These folds are not traceable northwest of this area.

Santa Rosa Valley seems to be a structural trough brought about by the uplift and eastward tilting of the San Francisco-Marin block, and the uplift of the Berkeley Hills block, bordering Santa Rosa Valley on the east. It may be in part synclinal, because there are steep west dips on the eastern margin of the valley and gentle east dips on the western margin. Minor folding or faulting in the valley is revealed by drilling.

Geologic History

The earliest geologic event recorded in the Sebastopol quadrangle is the deposition of the Franciscan-Knoxville group of Upper Jurassic age. However, just west and south of the quadrangle, at Bodega Head and Point Reyes peninsula, there are exposures of granitic and metamorphic rocks of the Sur series, which are possibly Paleozoic or older. Although these older rocks only crop out west of the San Andreas fault, they probably comprise, at least in part, the basement upon which the Franciscan-Knoxville group rests.

In Upper Jurassic time this area was apparently part of a broad slowly sinking geosyncline in which was deposited the great thickness of sandstone and shale of the Franciscan-Knoxville group. Submarine volcanism accompanied deposition of these sediments, as basic lava flows were poured out on the sea floor and in places intruded into the sands at shallow depths. Silica, concentrated in the sea water as a result of volcanism, was precipitated to form numerous lensoid bodies of chert. At a later stage in their depositional history the deeper portions of the sediments were intruded by basic and ultrabasic igneous rocks, which in some places metamorphosed the intruded rock.

Table 5. Partial Log of Ramondo No. 1 (Elev. 85 feet).
(Courtesy of E. W. Lenhart)

Rock	Depth (feet)
Buff sand	35
Blue gumbo clay with sand streaks	65
Thin layers of asphaltic mat	66
Blue clay	290
Grit in blue clay	300
Gas show	700
Bright greenish-blue clay	750?
Logs; pulpy, soft mat; redwood-like bark	785
Pea gravel, (3/8″ average diameter)	825
Shell layer	----------
Shells in blue sandy clay	900
Shells in reef	1,190
Hot area	1,260
Oil show, pebbles up to 2 inches in diameter	1,450
Blue fine sand and shale	1,460
Hot area	----------
Log, redwood?	----------
Blue sand, clay, shale	1,475
Turquoise clay with black matter	1,530
Blue clay sand shale	1,630
Spots of bentonite	----------
	2,100 ± total

The absence in this quadrangle of deposits representing the long interval between Upper Jurassic and middle Pliocene time makes it impossible to outline in detail the events which took place during this interval. In middle Pliocene time a basin was developed along the present site of Petaluma Valley and in it clay, with interbedded fine-grained conglomerate and sand, was deposited. The presence of brackish-water mollusks in these sediments indicates that the basin was depressed enough at times to allow sea water to enter, probably from the southeast. At other times a fresh-water lake probably occupied this basin.

Following deposition of the Petaluma formation, tectonic activity increased and culminated in a severe diastrophism in late Pliocene time, when the block south of the Tolay fault was uplifted several thousand feet and the Petaluma formation removed from it. On the north side of the fault, the Petaluma formation was strongly folded. Erosion of the San Francisco-Marin block during and after this orogeny developed a topography of late maturity or early old age, marked by relatively low rounded hills and broad valleys.

In upper Pliocene time the area was depressed, possibly by broad warping, and covered by the sea in which the Merced formation was deposited. At this time, farther eastward, volcanic activity began, and lava flows and pyroclastics of the Sonoma volcanics were emitted in great volume. These flows spread out over the Petaluma formation and the Franciscan-Knoxville rocks bordering the Tolay fault, which was apparently still active. Fluvial sands and gravels were deposited between flows. A burst of explosive volcanic activity spread ashes and pumice over the Merced sea. These ashes, combined with debris brought in by streams, formed a tuff breccia as much as several feet thick in marine Merced sediments. A volcanic vent developed at Roblar, but apparently did not erupt any large amount of material. The land bordering the Merced sea was relatively low and, in part, wooded. Fluvial and strand-line conglomeratic and medium-grained sand and some silt accumulated along the eastern margin of the sea. Carbonaceous material including some logs, were buried in these deposits and locally formed coal beds.

The deposition of the Merced formation may have extended into Pleistocene time, for there is no adequate means to date the upper limit. The history of the region in the Pleistocene epoch has been mainly one of uplift and minor settling. Patches of Merced sandstone west of Occidental at elevations over 1100 feet testify to the great amount of uplift that has occurred.

Several stages in the Pleistocene uplift of the San Francisco-Marin block are represented by numerous marine terraces along the coast and by a 100 foot terrace in Santa Rosa Valley. Recent minor sinking (or rise in sea level) is evidenced by the drowned features of Estero San Antonio, Estero Americano, and the mouths of Salmon Creek and the Russian River. These streams are affected by the tide far inland from their mouths, and have alluviated valleys, even where they pass through narrow canyons near the ocean.

ECONOMIC GEOLOGY

The chief mineral products mined in the Sebastopol quadrangle are sand and gravel, produced chiefly along the Russian River, and crushed stone, produced from numerous small quarries. Chromite, copper, coal, building stone, tuff, gold, and garnet have been mined at one time or another. Quicksilver, oil and gas have been prospected for, but no economic deposits of these commodities have been reported. All known mines, quarries, and prospects are located on the accompanying economic map (pl. 2).

Chromite

Several chrome workings are located in outcrops of the Camp Meeker serpentine sill. All but one are prospects, having no recorded shipments of ore.

Sonoma Chrome, Inc., mine is in secs. 15, 16, and 17, T. 7 N., R. 10 W., M.D., 3½ miles north of Occidental. It is owned by Florence M. Button, of Camp Meeker, California.

The ore occurs as small kidneys of chromite which strike about N. 40° W. and are parallel to the schistosity of the serpentine country rock. A shaft 55 feet deep, drifts, pits, and trenches were used to develop this mine. Production came mostly from a large open cut.

In 1918 the property, then called the Meeker mine, was leased to S. H. Dolbear, who mined and shipped 644 long tons of ore containing 39 to 42 percent Cr_2O_3. In 1942 a 2000-acre tract of this land was leased to Bentley Newman of Santa Clara, who, after obtaining a loan from the Reconstruction Finance Corporation, cleaned out the shaft and old chromite workings and repaired the road. Evidently not enough ore was developed to warrant further work, because on expiration of the lease in 1952, no ore had been mined.

The high-grade ore is said to contain from 42 to 51 percent Cr_2O_3 with about 3 : 1 ratio of Cr : Fe. Dow and Thayer estimated the reserves to be less than 5000 long tons. The property is idle.

Petroleum

Gas seepages and small oil slicks occur in Santa Rosa Valley northeast of Sebastopol, and gas is reported in wells in the lower part of Green Valley Creek. Residents near Bloomfield claim that gas is a serious problem in pumping their deep water-wells. In 1937 a well was drilled a mile or so south of Two Rock by the Two Rock Oil Corporation. After drilling 475 feet into Franciscan-Knoxville rocks, it was abandoned. In 1948 a well was drilled 300 feet south of Hall school, northeast of Sebastopol. This well has been temporarily abandoned after reaching about 2100 feet, the limit of the portable rotary-rig being used. A partial log of this well is given in table 5.

Sand and Gravel

Mirabel Sand & Gravel Company is located in the NW¼ sec. 31, T. 8 N., R. 9 W., M.D., half a mile northwest of Mirabel Park. Operator is Simon Camgros, San Rafael, California.

Sand and gravel has been taken from this area since 1927 by Simon Camgros, who is the present owner and operator of the plant. Most of the product of the washing plant is used as concrete aggregate by a ready-mix concrete plant in San Rafael which is also owned by Mr. Camgros.

Sand and gravel is taken from the river and beach of the Russian River by two slackline cable excavators and one Northwest dragline. One scraper delivers directly to the washing plant, and the other scraper and the dragline load into trucks which dump into an elevator at the base of the washing plant. The river-run material is washed and sized, then stored in concrete bunkers from which it is loaded by gravity into trucks for delivery. The washing plant has a capacity of about 400 cubic yards per shift, and the products are as follows:

Size	Cubic yards
Sand	250
4/16-inch pea gravel	25
½-inch pea gravel	15
¾-inch gravel	75
1½-inch rock	30

Each year the sand and gravel previously removed is replaced during the period of high water. The material consists of sandstone, chert, quartzite, and serpentine. The particles are well-rounded and have a high strength.

When working behind the dams the slackline cable excavators have limited use and most of the loading into trucks is done by the dragline. When the dragline is inoperative the washing plant is supplied with river-run gravel by a bulldozer which feeds from a stock pile into the elevator boot. The capacity of the present equipment of this company is about 1000 cubic yards of river-run gravel per shift. Eight men are employed in this area by the Mirabel Company.

Crushed Stone

Crushed stone is produced intermittently from many small quarries, largely located in outcrops of Franciscan-Knoxville rocks. Rock types used include chert, silty chert, greenstone, sandstone, serpentine, and tuff breccia. The product is used locally in road construction. At one time a tunnel was driven into a quartz vein in Franciscan-Knoxville rocks just north of Dunham school, the quartz being crushed and sold for chicken grit.

Water

Problems of water supply vary widely in the Sebastopol quadrangle. The rapid growth in population in recent years has developed water supply problems in areas where water at shallow depth has previously been plentiful.

The porous sands and gravels of the valley alluvium in Santa Rosa Valley and of the Merced formation in the eastern valley border section are excellent aquifers and, in general, adequate water supply may be obtained at reasonable depths in these areas. In most places a supply of water adequate for domestic use may be secured from wells between 25 and 50 feet deep. Larger supplies, as for small ranch use, may be obtained between 100 and 200 feet. For irrigation purposes, for 5 or more acres, wells from 400 to 600 feet deep are necessary in most places. Near the mouth of Mark West Creek, a hop grower uses a 1300 foot well (in the Merced formation) to supply irrigation water. In the valley border section much of the water from the deeper wells is unfit for drinking and, in many places, two wells are maintained. Areas where Franciscan-Knoxville rocks are exposed present the most difficult problems of water supply. Natural springs and shallow wells in valley alluvium are depended on for water in these areas, but many are barely adequate for domestic use. A thick mantle of soil and rotten rock serves as an aquifer to some extent, but it also supports a lush vegetation which is a powerful drain on the water supply. Fault and shear zones, fractures, and joint systems control ground water to some extent, but are so erratic that it is not safe to project them very far with the hope of tapping a reservoir at depth. The best sources of water in this area are developed springs and wells drilled after a detailed examination of the locality for spring patterns or shear zones.

The plateau section is also one in which water supply is a problem for most residents. The plateau is covered by the Merced formation, but the formation does not contain the abundant supplies of water found elsewhere. Although water is more easily obtained here than in areas of Franciscan-Knoxville rocks, the need for larger amounts for dairies, ranches, and cultivation emphasizes the limited quantities. Most wells for domestic use in this area are sunk in valley alluvium and are about 25 feet deep. Springs are not uncommon due to the alternation of pervious with impervious, nearly horizontal beds, and many residents develop these, especially for stock use. Other wells for domestic use are commonly 200 or 300 feet deep. East of Valley Ford, a copious supply of water may be obtained between 300 and 400 feet (Merced formation), according to Mr. Clarence Woodbury, a driller who has drilled many wells in this area. At shallower depth a supply barely sufficient for domestic use is all that is obtained. Northeast of Two Rock, the Merced formation includes small lenses of gravel and coarse sand which are excellent aquifers, especially where they rest on basalt flows or Franciscan-Knoxville rocks.

Some residents west of Dunham school have tried horizontal drilling into hillsides near springs. Only two small borings had been made up to the time of this writing, but satisfactory results were reported and plans were being made for more extensive drilling.

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STATE OF CALIFORNIA
DEPARTMENT OF NATURAL RESOURCES

DIVISION OF MINES
OLAF P. JENKINS, CHIEF

Base from United States Geological Survey 1933 and 1935

Geology surveyed in 1948-49

ECONOMIC MAP OF THE SEBASTOPOL QUADRANGLE, CALIFORNIA

By Russell B. Travis

Scale 1/62500

Contour interval 25 feet
Datum is mean sea level

MAP LEGEND

SEDIMENTARY ROCKS

QUATERNARY

- Landslide
- Alluvium
- Older alluvium
- Terraces (marine and fluvial)
- Sand dunes

TERTIARY — Pliocene, Upper

- Merced formation (fine-grained massive marine sandstone, conglomeratic in part. Includes tuff-breccia bed (Tmt))

UNCONFORMITY

TERTIARY — Pliocene, Middle or upper

- Petaluma formation (thin bedded green and buff diatomite clay)

JURASSIC — Upper Jurassic (Franciscan-Knoxville group)

- Knoxville (?) formation (dark gray, thin bedded, silty shale)
- Franciscan-Knoxville undifferentiated (sandstone, graywacke, minor shale, conglomerate, chert (Jfc), basic volcanics and diabase)
- Metamorphic rocks (largely glaucophane and related schists)

IGNEOUS ROCKS

TERTIARY — Pliocene (Sonoma volcanics)

- Upper (?): Vent breccia (rhyolite)
- Upper: Basalt

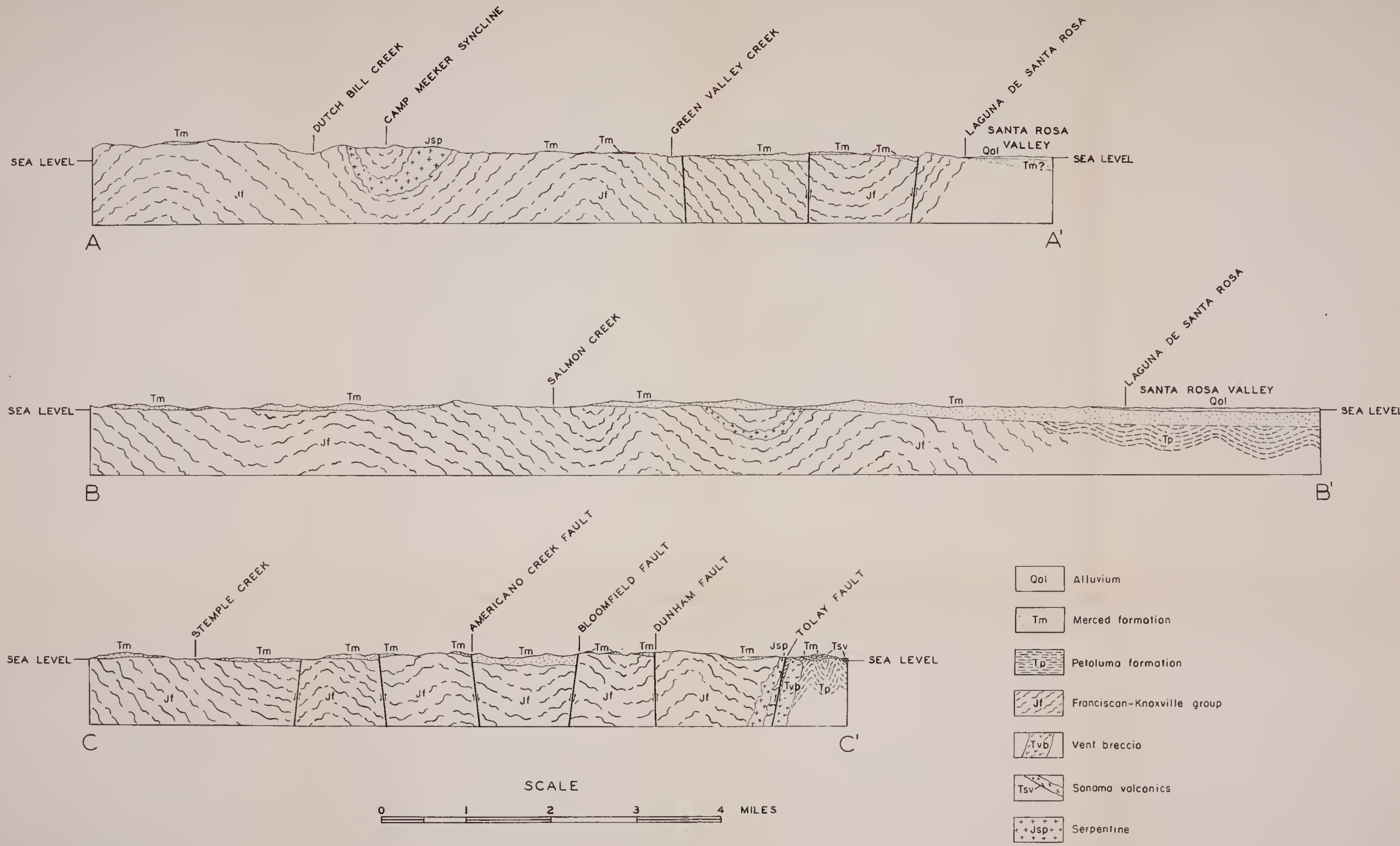
JURASSIC — Upper Jurassic (Franciscan group)

- Greenstone (altered diabase and basalt)
- Serpentine (includes pyroxenite and silica-carbonate rock)

SYMBOLS

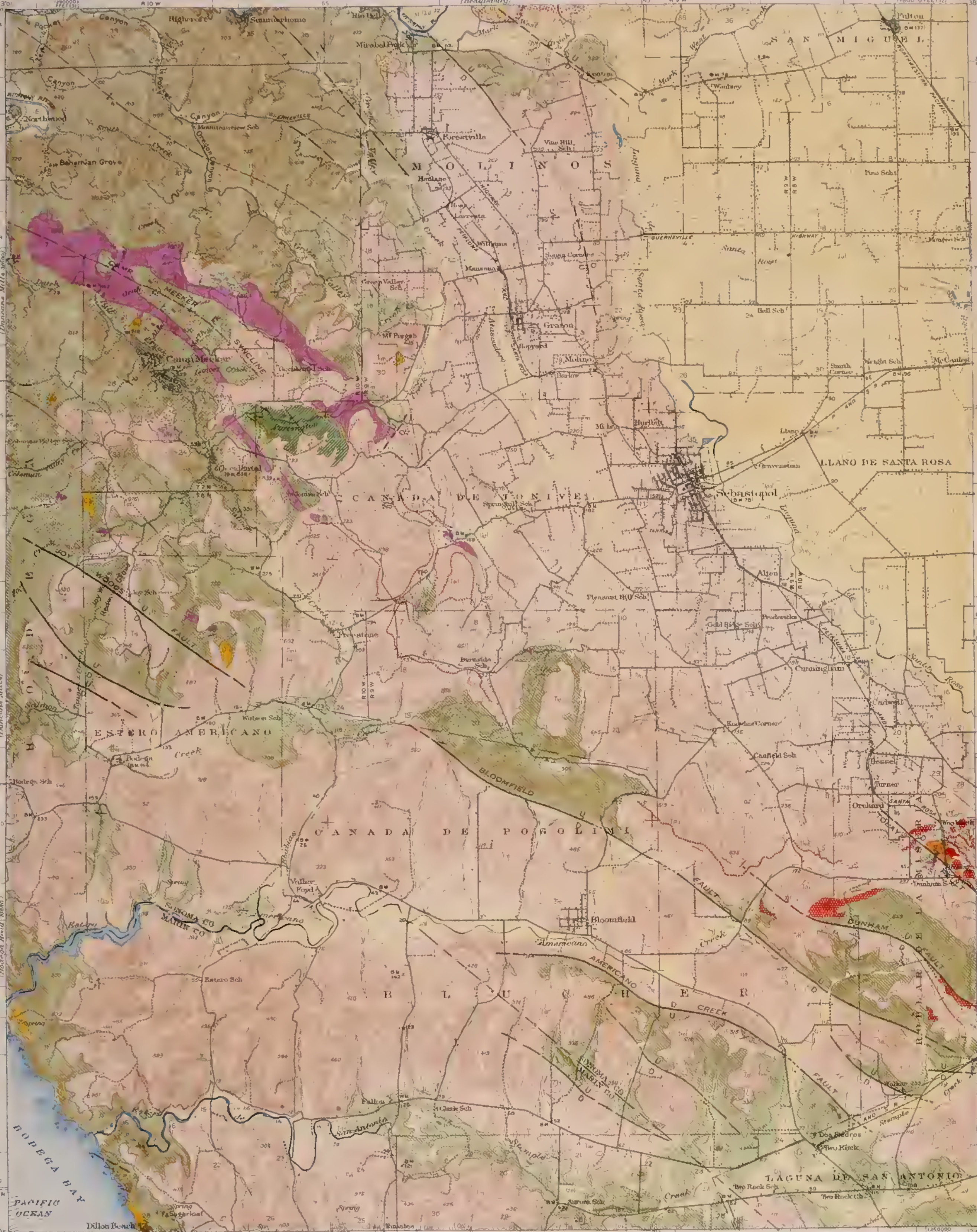
- Alluvium and terrace boundaries
- Contacts (dashed where inferred)
- Faults (dashed where inferred, dotted where concealed. U, upthrown side; D, downthrown side)
- Hypothetical or doubtful fault
- Axis of anticline (dashed where inferred; dotted where concealed)
- Axis of syncline (dashed where inferred; dotted where concealed)
- Dip and strike of beds
- Strike of vertical beds
- Horizontal beds
- Sand and gravel pit
- Mine or quarry
- Prospect
- Dry hole

Abbreviations. Au=gold; Cr=chromite; Cu=copper; g=garnet; Hg=quicksilver; r=rock; Si=quartz.



GEOLOGIC SECTIONS OF THE SEBASTOPOL QUADRANGLE

BY RUSSELL B. TRAVIS



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(Calistoga)

COLLATE:
3 PIECES